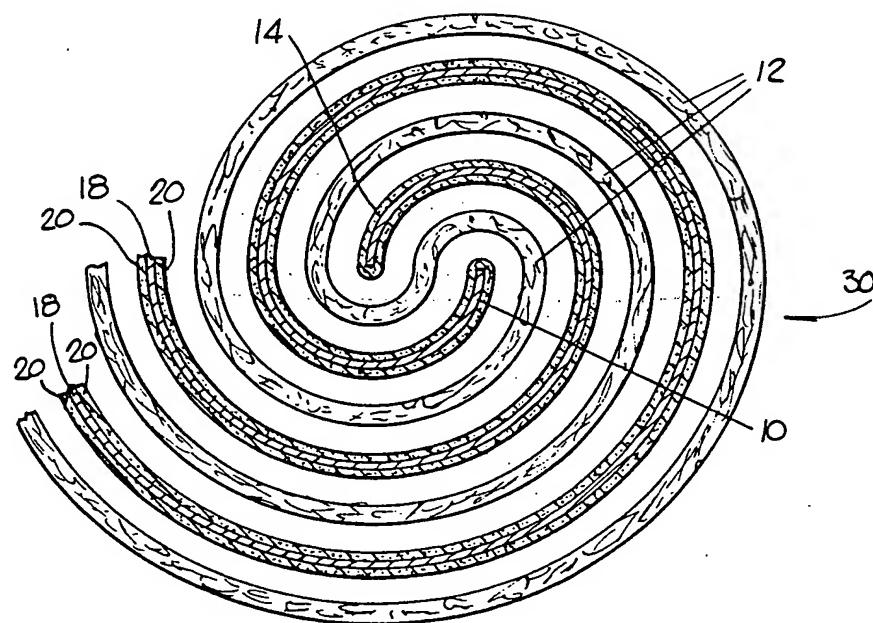


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(54) Title: ULTRA-THIN PLATE ELECTROCHEMICAL CELL AND METHOD OF MANUFACTURE



## (57) Abstract

This invention relates to electrochemical cells having superior recharge and discharge capabilities and to a method for the production of the cells. The cells are characterized by the use of ultra-thin non-perforated negative and positive films (18) of lead or nickel to be used in lead acid and nickel cadmium systems. The method includes the use of a single sheet of separator material (12) that has been infiltrated with electrolyte prior to its spiral winding onto a mandrel.

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Ultra-Thin Plate Electrochemical Cell and  
Method of Manufacture

Field of the Invention

This invention relates to electrochemical cells having superior recharge and discharge capabilities and a method for manufacture of such cells. Such electrochemical cells are comprised of ultra-thin spirally wound plates contained within a hermetically sealed container.

Background of the Invention

There have been dramatic improvements in the design and performance characteristics of compact hermetically sealed rechargeable electrochemical cells. These cells are typically configured either as a series of plates or in a spirally wound electrode assembly. The two commonly used chemical systems are the lead acid system and the nickel 10 cadmium system.

Although the lead acid battery system has been known and utilized for many decades, solutions to many of the practical difficulties associated with using such cells were not proposed until the 20 mid-1970s. One of the difficulties seen with early lead acid cells was related to the problem of keeping the electrolyte acid contained within the cell. It was necessary to maintain an excess amount of acid (generally sulfuric acid) in the cell in order to allow for overcharging of the electrodes 25 during the recharge process. Overcharging leads to the production of hydrogen and oxygen within the cell which traditionally was vented from the cell. Electrochemical cells having vent means and free acid generally had to be held upright in order to prevent the acid from leaking from the cell.

An additional problem with traditional lead acid cells was in maintaining the physical

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characteristics of the lead plates within the cell. Pure lead has some fluid flow and is also relatively flexible. In order to put some "back bone" in the lead plates, lead containing up to one percent of 5 calcium was often used in cells. The calcium in the lead gives the plates some rigidity, but significantly reduces the efficiency of the discharge/recharge chemistry.

The breakthrough invention in lead acid 10 cells is described in United States Patent No. 3,862,861 of McClelland et al. The McClelland patent discloses the incorporation of several 15 elements that combine to alleviate each of these problems associated with the traditional lead acid cell. The McClelland invention recognized the potential of utilizing the electrochemical recombination reaction between the oxygen and 20 hydrogen formed during overcharging to maintain a balanced system. By capitalizing on the "oxygen cycle", a lead acid cell could be produced such that 25 the electrolyte could be maintained in a "starved" condition. Rather than having an excess of electrolyte, the cell could be operated with a minimal amount of electrolyte present in the system. In order to maintain a starved condition, it is necessary to have sufficient absorbent material or 30 pores within the cell to contain the electrolyte.

By using relatively absorptive separator material, McClelland was able to accomplish two distinct functions. The absorptive separator allowed the flow of gases and electrolyte between the positive and negative plates, thereby allowing the oxygen cycle to function. The absorptive separator also acts as a wick to hold the

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electrolyte within the cell without the necessity of having free electrolyte in the system.

McClelland also discloses a configuration of the plates and separator so that the elements are held tightly together. Fluid flow of the lead is thus prohibited. It was then possible to use considerably purer lead grids that are electrochemically more efficient than the calcium containing lead plates previously used. Venting means are included in the McClelland device as a safety release device in case, through some malfunction, gases generated during recharging were not reconverted to water. However, since there is little or no non-absorbed electrolyte in the cell, there is almost no danger of acid leaking from the cell.

Prior to the development of the McClelland device, United States Patents Nos. 3,395,043 and 3,494,800 of Shoeld disclosed the use of relatively thin lead plates in an electrochemical cell. The cells described in the Shoeld patents, being prior in time to the McClelland patent, did not use absorptive, gas permeable separators. The cells disclosed did not, therefore, utilize the oxygen cycle, were not maintained in a starved or semi-starved condition, and probably contained free electrolyte in order to function properly. The Shoeld patents do not indicate that the batteries produced would have superior discharge or recharge characteristics. Based on the techniques and materials available at the time of the Shoeld disclosures, it is quite unlikely that the cell disclosed therein would have had any significant advantages over existing cells.

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Since the McClelland patent, there have been several patents disclosing improvements to the fundamental cell disclosed therein. For example, United States Patents Nos. 4,465,748 of Harris, 5 4,414,295 of Uba, 4,233,379 of Gross, 4,137,377 of McClelland and 4,216,280 of Kono each describe separators to be used in starved lead acid cells. United States Patents Nos. 4,725,516 of Okada and 10 4,648,177 of Uba both identify cell parameters that lead to superior recharge/discharge characteristics in lead acid cells.

United States Patent No. 4,769,299 of Nelson to a certain extent incorporates the inventions of Shoeld and McClelland. The Nelson patent describes 15 the use of grid-like plates and absorptive gas permeable separators as described in McClelland with the extremely thin plates disclosed by Shoeld. The result is a lead acid cell with enhanced recharge/discharge properties.

20 The theoretical advantage of utilizing thin plates in electrochemical cells has been known for decades. The thinner the plates the less distance electrons have to travel within the plate during discharge, and, during recharge, the shorter 25 distance of non-conductive material to be regenerated. To a certain extent, the thickness of plates utilized has been dictated by the available technology for the production and handling of thin lead films.

30 For much the same reasons that thin plates produce superior results, thin layers of reactive paste also lead to superior discharge/recharge characteristics. The Nelson patent discloses the use 35 of both thin lead grids and thin layers of reactive paste. A basic shortcoming in the Nelson device, is

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that the paste residing within the grid openings can have a greatly increased distance to the lead plate material. For example, in the Nelson patent the openings in the lead plate grid are constructed so 5 that the distance from the center of the grid to the grid strands is significantly greater than the thickness of the paste layer on the face of the plate. Since the performance characteristics of 10 electrochemical cells is proportional to the thickness of the lead plates and the thickness of the paste layer, the use of grids greatly decreases the efficiency of the cells.

Typically, spirally rolled electrochemical cells are designed so that tabs are periodically 15 incorporated into the plates--the tabs of one polarity going one way, the tabs of the opposite polarity going the other--in order to make connections from the plates to the cell terminals. This arrangement creates a problem in high rate 20 discharge cells. The rapid discharge of substantial amounts of power generates a significant amount of heat along the tabs and terminals due to the relatively high resistance of the arrangement. United States Patent No. 4,322,484 of Sugalski 25 describes the use of an additional element within the cell to act as a heat sink.

Although there have been significant advances in the field of electrochemical cells, the theoretical possibilities for such systems have not 30 been met.

There are a number of patents describing continuous processes for the manufacture of electrochemical cells and apparatus for performing the same. None of these processes are without some 35 problems. In particular, adopting these processes

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for use with ultra-thin plates utilized in the electrochemical cells of the present invention would be extremely difficult. Examples of such processes and apparatus are described in the following 5 patents:

	<u>United States Patent No.</u>	<u>Inventor</u>
	4,648,177	Uba <u>et al.</u>
	4,606,982	Nelson <u>et</u>
	<u>al.</u>	
10	4,212,179	Juergens
	4,158,300	Hug <u>et al.</u>
	4,112,202	Hug <u>et al.</u>
	4,099,401	Hug <u>et al.</u>
	4,064,725	Hug <u>et al.</u>
15	3,494,800	Shoeld

#### Summary of the Invention

The electrochemical cell of the present invention is characterized by the use of ultra-thin 20 non-perforated electrode plates along with ultra-thin active material layers and thin absorptive separator material layers. In the optimum device, the electrolyte is initially produced with an excess of electrolyte, but through processing, a volume of 25 electrolyte is achieved in the cell, and the electrolyte volume is maintained in an almost saturated condition with respect to the absorptive capacity of the separator and the electrode materials.

In the present invention electrochemical 30 cells are produced utilizing non-perforated sheets of lead or nickel approximately .002 inches thick. The active material or paste maintained on the 35 surface of both sides of the sheet are approximately .002 to .003 inches thick. The inter-plate spacing

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is .005 to .007 inches. The cell of the present invention is further characterized by an exceptionally high plate surface area to active material ratio.

5 When using lead acid cells, the active material may be sulfated lead pastes or PbO and Pb<sub>3</sub>O<sub>4</sub> for the positive and PbO for the negative plates. When utilizing sulfated pastes, the specific gravity of the electrolyte is about 1.28.  
10 The lead plates are greater than 99% pure. If containing tin, the lead may be 99.50% pure lead and .50% tin. If tin is not used, the lead is approximately 99.99% pure.

15 Any number of separator materials known in the art may be utilized with the present invention. One suitable glass microfiber material consists of 90% of fibers of 1 to 4 microns in diameter and 10% of fibers being larger fibers existing as a woven or oriented mat.

20 In one embodiment of the electrochemical cells of the present invention, the surface of the electrode plates is either physically roughened or chemically etched to increase the adhesion of the thin layer of active material to the plate surface.

25 The electrochemical cell of the present invention is further characterized by an improved terminal electrode attachment assembly. According to the invention, one continuous edge of the electrode plate is in contact with the cell terminal, resulting in an efficient low resistance conductive pathway that reduces the build-up of excess heat in a rapid discharge cell.

30 The electrochemical cell of the present invention demonstrates dramatic improvements in recharge/discharge capabilities over cells produced  
35

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as described in the various references cited above. Maximum current capability is increased and the current value remains at near its maximum throughout a longer period of its discharge profile. Recharge 5 times are also reduced dramatically. Recharge can be accomplished at up to 10C (or ten times the amperage of the cell), as long as the cell is not overcharged.

10 The electrochemical cell of the present invention is manufactured utilizing a unique combination of process elements. In one embodiment of the present invention, the mandrel into which the cell is spirally wound is adapted in order to allow the use of a single sheet of separator material.

15 The plates of the cell are coated with the appropriate electrochemically active paste prior to insertion into the mandrel apparatus. The separator sheet is infiltrated with electrolyte prior to winding, thus eliminating the need to add 20 electrolyte to the system after winding. Such infiltration can be accomplished by running the absorptive separator material past porous ceramic rollers that have a precisely metered amount of electrolyte flowing to the outside surface of the 25 roller.

30 Following the winding process, the loose ends are severed, and the spirally wound unit cell is secured, placed in a polypropylene sleeve and ultimately in a metal can. The terminal electrode assemblies are secured to both ends of the cell prior to introduction of the cell into the environmentally secured cans.

Brief Description of the Drawings

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FIG. 1 is a diagrammatic vertical cross-sectional view of a pair of cell units according to one embodiment of the present invention.

5 FIG. 2 is a diagrammatic horizontal cross-sectional view of a spirally wound cell unit according to one embodiment of the present invention.

10 FIG. 3 is a plan view of an embodiment of a terminal connector according to the present invention.

FIG. 4 is a plan view of an alternative embodiment of a terminal connector according to the present invention.

15 FIG. 5 is a diagrammatic vertical cross-sectional view of a portion of a spirally wound cell unit according to one embodiment of the present invention.

20 FIG. 6 is a partial cross-sectional view of the terminal portion of an embodiment of the cell unit of the present invention.

FIG. 7 depicts discharge curves comparing cells of this invention with conventional cells.

25 FIG. 8 is a schematic depiction of a winding apparatus as it is winding cell components in a spiral form.

FIG. 9 is a view of the mandrel of the present invention.

30 FIG. 10 is a depiction of the process used in placing the connector on a cell of the invention.

#### Description of the Preferred Embodiments

According to the present invention, an electrochemical cell having both excellent charge and discharge characteristics is described.

35 Technological breakthroughs in the fields of thin

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film handling have made it possible to create high rate electrochemical cells that have performance characteristics that are unprecedented in the field.

Utilizing ultra-thin non perforated films of either lead (for lead acid systems) or nickel (for cadmium nickel systems) in combination with extremely thin layers of active material, it is possible to create cells that have very high utilization of the active material, even at extreme discharge rates. Therefore, even under extreme 10 loads there is virtually no voltage drop within the plates of the cell.

An additional benefit provided when utilizing such ultra-thin plates, is that the increased amount of film cross-sectional area provides a large heat sink for heat generated during discharge. In many rapid rate discharge cells, heat build-up can be substantial. The present invention describes electrochemical cells with quite low 20 current densities, thereby reducing heat creation.

The electrochemical cell of the present invention is composed of ultra-thin non-perforated films of an electrochemically active metal -- generally lead or nickel -- that is coated on each 25 side with an electrochemically active paste. The positive and negative "plates" of the electrochemical cell are maintained apart from each other by separator material. The separator material also acts to absorb the electrolyte that is contained with the enclosed cell system.

A diagrammatic view of a cell unit according to the present invention is seen in FIG. 1. Positive plate 10, separator 12 and negative plate 14 constitute an electrochemical unit cell 16. Both 35 the positive plate 10 and the negative plate 12

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consist of an ultra-thin film 18 of either lead or nickel partially coated on both major faces with a layer of a suitable electrochemically active paste 20.

5 It is important that the film not only be extremely thin, but that it not be perforated. One of the more critical elements of the present invention is that there not be any active material paste 20 at a distance of greater than .005 inches 10 from the film 18 on which it is coated.

According to the present invention, the films 18 utilized in the electrochemical cell are no greater than .005 inches thick. In the preferred embodiments, the films 18 are about .003 to .0015 15 inches thick. Handling such thin films and incorporating the same into functional electrochemical cells was previously thought to be impossible. In certain ways, the electrochemical cells of the present invention are constructed along 20 the lines of standard electrolytic capacitors.

Utilizing such thin films of active material, it is possible to greatly increase an important variable in such electrochemical cells, the ratio of surface area of film to the amount of 25 active paste material. In the present invention, cells having greater than 26.0 square centimeters of surface area to gram of active material are described.

A thin layer of the active material paste 20 30 is applied to a large portion of both major faces of the negative and positive films 18. Each layer is, at the most, .005 inches thick, and in the preferred embodiments of the invention, the layers of active material paste 20 are about .002 to .003 inches 35 thick. Both positive and negative plates 10, 14

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are, at the most, .01 inches thick and in the preferred embodiment have a thickness of about .005 to .008 inches, with an interplate spacing of about .005 to .007 inches.

5        In each unit cell 16, the positive plate 10, the separator 12 and the negative plate 14 are held against each other in a specific physical relation as seen in FIG. 1. Both major faces of the metal films 18 are coated with active material paste 20, 10 except along alternating horizontal edges 22, 24. On the positive plate 10, the portions of the major faces 26 adjacent to the upper horizontal edge 22 are not coated with the active material paste 20, and on negative plate 14, the portions of the major 15 faces 28 adjacent to the lower horizontal edge 24 are not coated with the active material paste 20.

20       The physical arrangement of plate 10, 14 and separator 12 is also shown in FIG. 1. For example, the positive plate 10 is positioned so that the uncoated portion 26 extends above both the negative plate 12 and the separator 12. To the top, the separator 12 extends beyond the negative plate 14 but not as far as the positive plate 10 and to the bottom, the separator 12 extends beyond the positive 25 plate 10 but not as far as the negative plate 14. It could, of course, be constructed so that the relative position of the positive and negative plates be reversed.

30       In an embodiment of the invention wherein a "D" size cell is produced, the negative and positive film 18 is about 1.5 inches high. The uncoated ends extend about 6-8 mm beyond the coated plate, and the separator 12 extends about 2-4 mm beyond the coated plate.

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The surfaces of the film 18 that are to be coated are preferably etched or roughened prior to application of the active paste 20. This allows for a more adequate adhesion between the paste and the film.

In the preferred embodiment of the invention, the electrochemical cell is constructed of a single spirally wound unit cell as is shown in FIG. 2. Of course, the invention could also be employed utilizing parallel stacks of any number of unit cells. In the spirally wound configuration 30, a single continuous sheet of separator 12 may be employed to separate the negative 14 and positive 10 plates from each other as seen in FIG. 2.

The preferred terminal connector 32 of the present invention is seen in FIG. 3. The terminal connector 32 is a component of the completed electrochemical cell formed near both the top (as seen in FIGs. 1 and 5, the positive terminal) and the bottom (as seen in FIGs. 1 and 5, the negative terminal) of the spirally wound plate and separator unit. The preferred terminal connector 32 is a conically shaped conductive element that is about the same diameter as the spirally wound cell, and that has a plurality of oblong shaped apertures 34 radiating outwardly from the center portion of the circle. The connector 32 may have a connector post 33 for ease in connection. An alternative connector 38 is seen in FIG. 4. This daisy-shaped connector has a plurality of radiating wings 82 protruding out from the body 84 of the connector 80.

A unit cell having the physical relationships as shown in FIGS. 1 and 2 and having terminal connectors 32 in place, is seen in FIG. 5. In the preferred embodiment, the connectors 32 are

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applied to the top and bottom of the cell (where the uncoated portions 26 and 28 of the negative and positive plates are extending out co-planarly) in a spiral configuration. The effect of such a motion requires that the uncoated portions 26 and 28 are bent radially inwardly. Due to the respective positions of the positive and negative plates 10, 14 and the separator 12, the uncoated portions 26, 28 contact each other and are separated from the opposite polarity plate by the separator 12, as seen in FIG. 4. It can be seen, therefore, that the relative physical positions of the plates and separator is critical in obtaining a proper connection between the terminal connector 32 and the uncoated portions 26, 28 of the plates.

The terminal arrangement of the present invention provides an improved means for maximizing contact between the respective plates 10, 14 and the terminal connector 32. The larger the surface area of each plate contacting the connector 32, the less resistance created in the system, and the less heat generated. In a preferred embodiment, the connectors 32 are permanently attached to the ends of the electrochemical cell by laser welding or plasma arc welding. The oblong apertures 34 are spaced to allow access to the interior surface of the connector 32 for welding.

An embodiment of the completed electrochemical cell terminal assembly 40 is seen in FIG. 6. The spirally wound unit cell 16 is held first in a polypropylene sealed container 42 and second in a stainless steel container 43 that is preferably equipped with vent means (not shown). The terminal connectors 32 are held in place by a torroidal brace 42, that holds such connectors 32 in

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contact with the exterior terminal 44. Insulation washer 51 insulates the exterminal terminal 44 from the stainless steel container 43.

When utilizing the lead acid system, the 5 lead nonperforated film 18 is preferably composed of lead that is at least 99.99% pure. In an alternative embodiment, the lead may be 99.50% pure and contain about .50% tin. As described above, the lead film 18 is .005 inches or less thick, and is 10 preferably about .003 to .0015 inches thick.

For lead acid electrochemical cells, there are a number of widely known combinations of active material pastes 20 that are typically used. Any of these commonly utilized systems would be appropriate 15 for use with this invention. For example, sulfated PbO pastes used on both the positive and negative plates provides a satisfactory system, as does the use of PbO and Pb3O4 on the positive plate and PbO on the negative plate. The use of sponge lead, 20 litharge, red lead or leady oxide is also possible. The only important factor is that the active material paste 20 be of a nature so that it can be applied to the ultra-thin lead film 18 in a consistently thin layer, as described above.

As is commonly seen in the new generation of 25 lead acid cells as exemplified in the McClelland and Nelson patents, the use of an absorbent separator 12 is critical. As described above, there are several separator materials that have been disclosed for use 30 specifically with lead acid system electrochemical cells. For the purposes of the present invention, any of the commonly used absorbent permeable separators will work suitably. In one preferred embodiment, the separator is a glass micro-fiber 35 wherein 90% of the fibers are 1-4 microns in

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diameter, and 10% of the fibers are longer (up to 1 inch in length), being 95% porous in the uncompressed state.

When sulfated lead oxides are used as the active material paste 20, the specific gravity of the sulfuric acid electrolyte solution used is between 1.20 and 1.32. Electrolyte concentration in the cell is established by adding an excess of electrolyte, and heating the cell in order to vent excess electrolyte. The type of vent used on the electrochemical cell may be similar to those described in the literature and known by those with ordinary skill in the art, and operates to vent excess gases when the internal pressure exceeds a certain level. The electrolyte remaining in the cell after heating and venting will be in an almost saturated state and some internal pressure (above atmospheric) will be maintained when in its normal operational state. In its operable state, the cell of the present invention is maintained so that the total void volume of the compressed separator and the active material is substantially filled, yet there is no free electrolyte present. The exact amount of electrolyte present in the cell, within these limits, is not critical to the functioning of the present invention.

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Example

As mentioned previously, electrochemical cells produced according to the present invention have distinctly superior discharge and recharge 5 capabilities. FIG. 7 shows the discharge curve for a lead acid electrochemical cell according to an embodiment of the present invention (C) in comparison with discharge curves for the cells described in United States Patent Nos. 3,862,861 of 10 McClelland *et al.* (A) and 4,769,299 of Nelson (B). As can be seen, the improved performance is more than just an incremental increase.

The electrochemical cell used to create the discharge curve seen in FIG 7 has the following 15 characteristics: The non-perforated lead film was composed of 99.50% lead and .50% tin; the lead films were .002 inches thick and were coated with a layer of .002 inches thick of sulfated pastes -- the total plate thicknesses being .006 inches; the electrolyte 20 was sulfuric acid with a specific gravity of 1.28; the glass micro-fiber separator was 95% porous in its uncompressed state and contained 90% 1-4 micron diameter fibers and 10% larger fibers up to 1 inch in length and has a surface area of about 2 m<sup>2</sup>/g. 25 In a "D" sized electrochemical cell, the lead films would be 45 inches long and 1.5 inches high, and there would be about 26.0 cm<sup>2</sup> of surface area for each gram of active material paste.

FIG. 8 shows the basic elements required in 30 one embodiment of the manufacture of electrochemical cells of the present invention. The central element of the process is the rotatable mandrel 50. The mandrel 50 is characterized by a continuous cavity 52 that is capable of receiving the separator 12 35 during the winding process.

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Drag Rollers 54 are positioned in order to smoothly facilitate the movement of the separator 12 towards the mandrel 50. The drag rollers 54 also act to assure that the plates are wound tightly as the cell is being formed. The unique mandrel design 5 allows the utilization of a single sheet of separator 12 to be used in each unit cell. Porous ceramic rollers 56 through which the separator must pass are also shown.

In a preferred embodiment of the invention, 10 the ceramic rollers 56 are associated with a reservoir 57 containing electrolyte. Metering means 58 are associated with the reservoir 57, that allow controlled amounts of electrolyte into the interior 15 area of the ceramic rollers 56. The ceramic rollers 56 are constructed such that electrolyte contained within its interior surfaces will flow to the surface of the rollers, where the electrolyte will be absorbed into the porous separator 12 that passes 20 between the rollers. By this procedure it is possible to assure that a precise amount of 25 electrolyte will be incorporated into the wound electrochemical cell. The amount of electrolyte added to the separator is small enough so that little if any electrolyte will be "squeezed" from the separator 12 during the winding process as the separator and plates 10, 14 are tightly wound together.

Of course, the electrolyte could be added to 30 the cell via conventional techniques. For example, after winding the cell and placement into a canister, liquid electrolyte may be added to the cell at this time.

The negative plate 14 is shown in FIG. 9 as 35 it is advanced toward the mandrel 50. The positive

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plate 10 is seen advancing toward the mandrel 50 from the opposite direction, and both being perpendicular to the general plane of the separator 12. The plates 10, 14 are both advanced toward the 5 mandrel 50 and held on a plate carriage 60. The plate carriages 60 act as conveyor belts to facilitate the advancement of the plates towards the mandrel.

10 The active material paste 20 is applied to both major faces of the plates 10, 14 -- as described above, so that certain areas of the major faces of the plates will not be coated -- at a point not shown. The application of the paste 20 may be accomplished by the use of a high pressure brush, or 15 a high pressure spray nozzle. After the active material paste 20 has been applied to the plates 10, 14, the plates are subjected to flash drying by infrared heat sources. The paste 20 as applied contains a relatively small amount of moisture, and 20 will dry adequately in a very short period of time.

25 In a preferred embodiment of the invention, some mechanism (not shown) is provided before the paste application zone in which the surfaces of the plates which are to be coated are scored or etched. Such scoring aids in the adhering of the active material paste to the plates, and can be accomplished via chemical or physical processes.

30 The plate carriages 60 are designed so that the front edge (the edge closest the mandrel 50) can be moved horizontally towards or away from the mandrel 50. It should be remembered that the plates of the present invention are extremely thin, even when coated, and will have little or no rigidity.

35 The production of the electrochemical cell proceeds through a series of steps. The process

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begins by placement of the separator around the drag rollers 54, through the opening in the mandrel 50 and between the two sets of porous ceramic rollers 56. The separator sheet must be long enough, both 5 above and below the mandrel 50, to supply sufficient separator for the entire electrochemical cell.

In a preferred embodiment, a single source of separator may be utilized either above or below the mandrel 50, and the initial step of the process 10 would be the threading of the separator through the ceramic rollers 56, past the first drag roller 54, through the opening in the mandrel and past the second drag roller 54. At this stage, the entire amount of separator to be used in the cell has been 15 infiltrated with electrolyte.

In an alternative embodiment, precut sections of separator may be utilized. In such an embodiment, the separator may be placed in the proper position by laterally moving the separator 20 between the various elements and having the correct amount of separator, both above and below the mandrel, for one cell unit. In this embodiment, the separator would have to be run through the electrolyte containing ceramic rollers prior to 25 being put in place relative to the mandrel.

Once the separator is in place, the mandrel is rotated about its axis one half turn (as seen by arrow A) so that the opening in the mandrel is now 30 in a horizontal position. At this point, the plate carriages 60 advance toward the mandrel 50 so that the plates 10, 14 will enter into the gap of separator created between the mandrel 50 and the drag rollers as seen in FIG. 9. The drag rollers 35 are then allowed to advance forward in order to engage the plates.

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FIG. 10 shows a detailed view of the mandrel 50 of the present invention. In association with the separator-receiving gap, is a clamp like device 80. The clamp 80 operates to facilitate the 5 securing of the separator into the mandrel 50 after it has been put in place. Once cell formation is completed, the clamp 80 releases, and the cell may be more easily removed from the mandrel.

Once the plates are engaged, the plate 10 carriages are moved horizontally away from the mandrel 50. The mandrel can now be rotated (counter clockwise in the example shown in FIG. 9), in order to create a cell unit. The drag rollers 54 create a certain amount of pressure against the expanding 15 diameter of the cell unit as it is being formed. The "tightness" of the winding will be controlled by a number of factors including: the speed of revolution of the mandrel 50; the tension exerted by the drag rollers against the growing cell, and the 20 source tension of the separator and plates relative to the mandrel 50.

As the desired diameter of the cell unit is about to be attained, the plates 10, 14 are cut off at the ends of the plate carriages 60 nearest the 25 mandrel 50. Tail wrap is attached to the ends of the plates and, once wrapped around the cell, may be heat sealed with a sizing roll or hot drag wires.

Once sealed in the spirally wound 30 configuration, the mandrel and drag rollers may be retracted and the cell may be incorporated into a useful means. The processing of the wound and sealed cell may be accomplished by procedures commonly known and available to those skilled in the art.

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As described above, and as seen in FIG. 11, the construction and manufacture of the connectors of the present invention is also unique. The cell is provided with positive and negative ends that 5 consist of the top and bottom portions of the spirally wound plates. The connector is put in place on the top and bottom of the cell by the application of a circular movement, forcing the flexible plate elements to press tightly against 10 each other to form an essentially continuous plate or cover above and below the spirally wound cell.

Once put in place on the cell via the circular motion, the connector is secured via arc welding or laser welding techniques. This 15 construction provides a low resistance pathway for electricity during recharge or discharge.

As should be clear from the above description, both the plates and the separator are being treated as they are being wound into the 20 mandrel. The plate is being coated with the active material, which is then flash dried -- all before reaching the mandrel and the growing cell. The separator is being impregnated with electrolyte as it passes between the porous ceramic rollers.

The present invention has applications in 25 all electrochemical cells, and in particular, the lead acid and nickel chromium systems. The descriptions given and the example presented are for the purposes of illustration and are not meant to 30 limit the claims of the application as set forth below.

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Claims

1. A rechargeable electrochemical cell comprising:

5 porous positive and negative plates; each having major faces and formed of an ultra-thin non-perforate film of metal partially coated with a layer of electrochemically active paste;

10 porous, compressible separator interposed between said positive and negative plates and compressed against the major faces of such plates to define, in combination, a cell unit, having first and second horizontal edges;

15 a containers encapsulating said cell unit; and

liquid electrolyte within said container.

2. The electrochemical cell of claim 1 wherein said plates have a thickness of less than .01 inches and said films have a thickness of less 20 than .005 inches.

25 3. The electrochemical cell of claim 1 wherein said plates have a thickness of less than .008 inches and said films have a thickness of less than .003 inches.

30 4. The electrochemical cell of claim 1 wherein the geometric surface area of said film is at least about 26.0 square centimeters per gram of said paste.

35 5. The electrochemical cell of claim 1 wherein said cell unit is spirally wound about a central axis and held tightly in a tubular configuration.

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6. The electrochemical cell of claim 5  
wherein on the first horizontal edge of said cell  
unit said negative plate extends beyond the edge of  
5 said separator, the separator extends beyond the  
edge of said positive plate and said negative film  
is not coated with said paste in the portion  
extending beyond said separator; and on the second  
10 horizontal edge of said cell unit, said positive  
plate extends beyond the edge of said separator,  
said separator extends beyond the edge of said  
negative plate, and said positive film is not coated  
with said paste in the portion extending beyond said  
separator.

15

7. The electrochemical cell of claim 6  
further comprising negative and positive terminal  
connectors, said negative connector adjacent to said  
first horizontal edge of said cell unit; and said  
20 positive connector adjacent to said second  
horizontal edge of said cell unit.

20

8. The electrochemical cell of claim 7  
wherein said terminal connectors are conductive  
25 cones containing a plurality of oblong radial  
apertures; said connectors secured to the portion of  
said plates extending beyond the said separator,  
such portion bending radially inward.

30

9. The electrochemical cell of claim 1  
wherein said electrolyte substantially fills the  
void volume of said separator and said active paste.

35

10. The electrochemical cell of claim 1  
wherein said electrochemically active paste is lead

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and lead dioxide, and said electrolyte is sulfuric acid.

5 11. The electrochemical cell of claim 10 wherein said lead is at least 99.99% pure.

12. The electrochemical cell of claim 10 wherein said lead is about 99.50% lead and .50% tin.

10 13. The electrochemical cell of claim 10 wherein said electrochemically active material is comprised of sulfated lead oxide paste.

15 14. The electrochemical cell of claim 13 wherein said electrolyte is sulfuric acid with a specific gravity of 1.20 to 1.32.

20 15. The electrochemical cell of claim 10 wherein said electrochemically active material coated on said positive plate is composed of PbO and Pb<sub>3</sub>O<sub>4</sub>, and said electrochemically active material coated on said negative paste is comprised of PbO.

25 16. The electrochemical cell of claim 1 wherein said metal is nickel and said paste is cadmium.

17. A rechargeable electrochemical cell comprising:

30 positive and negative plates, each having major faces, formed of a non-perforate film of electrochemically active metal partially coated with a layer of electrochemically active paste, the geometric surface area of said film being at least

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about 26.0 square centimeters per gram of said paste;

porous, compressible separator interposed between said positive and negative plates and compressed against the major faces of such plates to define, in combination, a cell unit;

5 a container encapsulating said cell unit; and liquid electrolyte within said container.

10 18. A rechargeable electrochemical cell comprising:

positive and negative plates, each having a major face, formed of a film of metal partially coated with a layer of electrochemically active 15 paste;

porous, compressible separator interposed between said positive and negative plates and compressed against the major faces of such plates to define, in combination, a cell unit having first and 20 second horizontal edges; said cell unit being spirally wound about a central axis and held tightly in a tubular configuration, on the first horizontal edge of said cell unit, said negative plate extends beyond the edge of said separator, the separator 25 extends beyond the edge of said positive plate, and said negative film is not coated with said paste in the portion extending beyond said separator; and on the second horizontal edge of said cell unit, said positive plate extends beyond the edge of said separator, the separator extends beyond the edge of 30 said negative plate, and said positive film is not coated with said paste in the portion extending beyond said separator; and

35 negative and positive terminal connectors, said negative connector adjacent to said first

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5 horizontal edge of said cell unit, and said positive connector adjacent to said second horizontal edge of said cell unit; said terminal connectors being conductive cones containing a plurality of oblong radial apertures; said connectors secured to the portion of said plates extending beyond the edge of said separator, such edges bending radially inward.

10 19. A process of making rechargeable electrochemical cells comprising:

inserting a sheet of separator at about at its lengthwise center point, through the opening of a rotatable mandrel;

15 rotating the mandrel on quarter turn, so that two openings exist, defined by the outside of said mandrel and said sheet of separator;

inserting the front edge of plate into each of said openings from opposite sides of said mandrel, so that said plates become engaged; and

20 spirally winding said plates and said separator by the rotation of said mandrel.

25 20. The process of Claim 19 further comprising:

securing the spirally-wound configuration of said cell; and

removing said cell from said mandrel.

30 21. The process of Claim 20 further comprising:

placing said removed cell in a stainless steel canister;

attaching positive and negative connectors to said cell with a rotatable motion in order to

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maximize contact between the edges of said plate and the connectors.

22. A process for attaching connectors to  
5 the negative and bottom portions of spirally wound  
electrochemical cells, said electrochemical cells  
comprised of positive and negative plates, each  
having major faces and formed of an ultra-thin non-  
perforate film of metal partially coated with a  
10 layer of electrochemically active past, separator  
interposed between said negative and positive  
plates, and wherein on the first horizontal edge of  
said cell unit said negative plate extends beyond  
the edge of said separator, the separator extends  
15 beyond the edge of said positive plate and said  
negative film is not coated with said paste in the  
portion extending beyond said separator; and on the  
second horizontal edge of said cell, said positive  
plate extends beyond the edge of said separator,  
20 said separator extends beyond the edge of said  
negative plate, and said positive film is not coated  
with said paste in the portion extending beyond said  
separator, comprising:

25 applying circular connectors unto the first  
and second horizontal edges of the spirally wound  
electrochemical cell in a circular motion wherein  
said uncoated portions of said plate are forced  
together; securing said connectors to said uncoated  
portions.

30

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23. A process of making electrochemical cells comprising:

coating substantially all of the major faces of positive and negative plates with a layer of electrochemically active paste, said uncoated portions corresponding to single horizontal edge of said plates;

assembling a cell unit consisting of a positive plate, a negative plate and a sheet of separator disposed between said plates, in such a matter that said uncoated portions are aligned opposite each other; and

attaching negative and positive connectors to the horizontal edges of said cells in a circular motion.

24. The process of Claim 23 wherein said cell unit is assembled such that such horizontal edge of said positive plate extends beyond the edge of said separator and said separator extends beyond the edge of said positive plate, and said horizontal edge of said positive plate extends beyond the edge of said separator and said separator extends beyond the edge of said negative plate.

25. The process of Claim 23 wherein said cell unit is assembled by spirally winding a single sheet of said separator and the negative and positive plate on a mandrel.

30

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26. A process of making electrochemical cells comprising:

coating substantially all of the major faces of a positive and negative plates with a layer of 5 electrochemically active paste, said uncoated portions corresponding to a single horizontal edge of said plates;

winding said plates unto a mandrel, separated by a continuous sheet of separator 10 material; and

attaching negative and positive connectors to the horizontal edges of said cells.

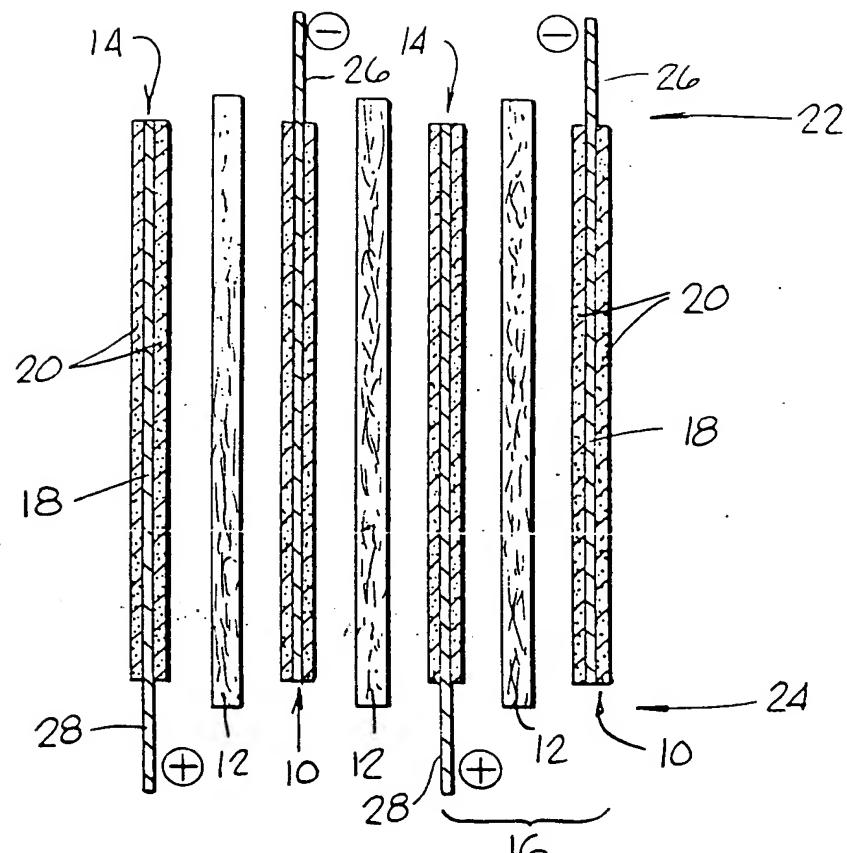


FIG. 1

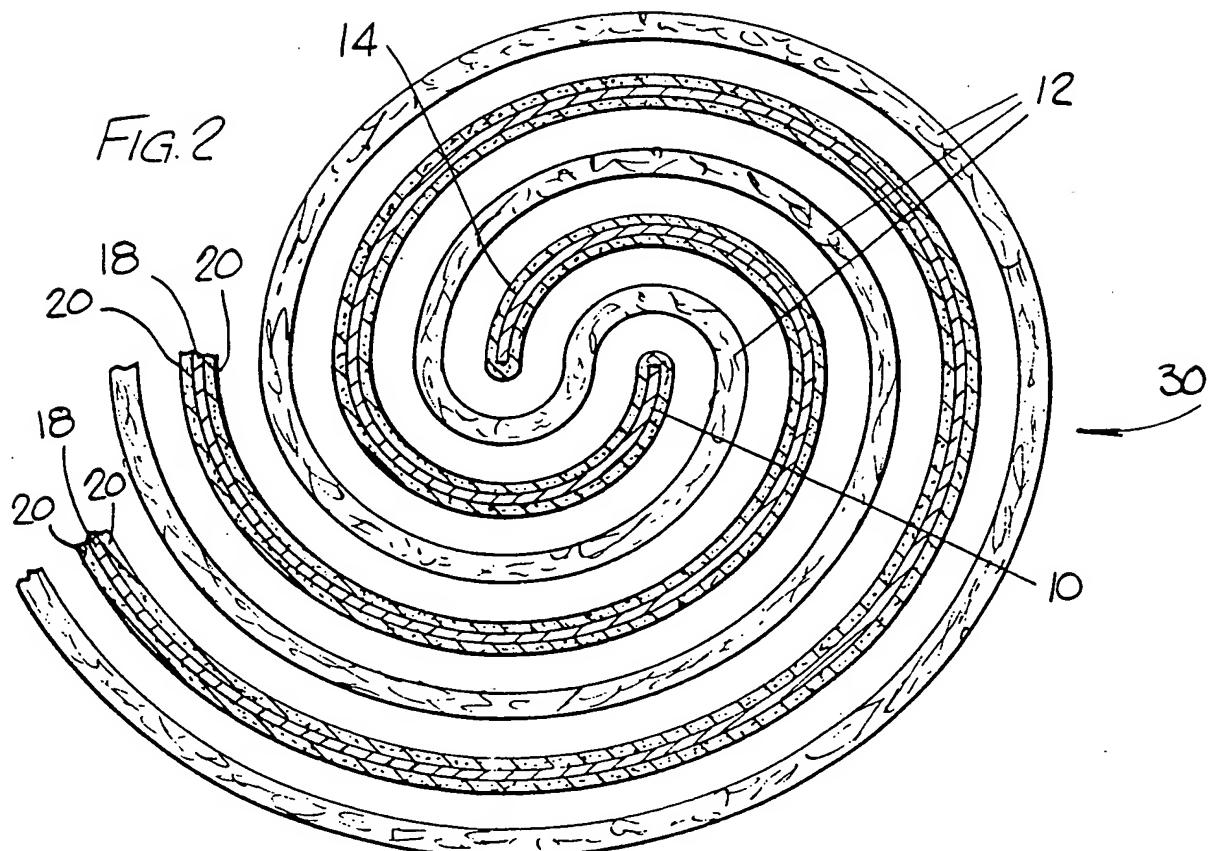


FIG. 2

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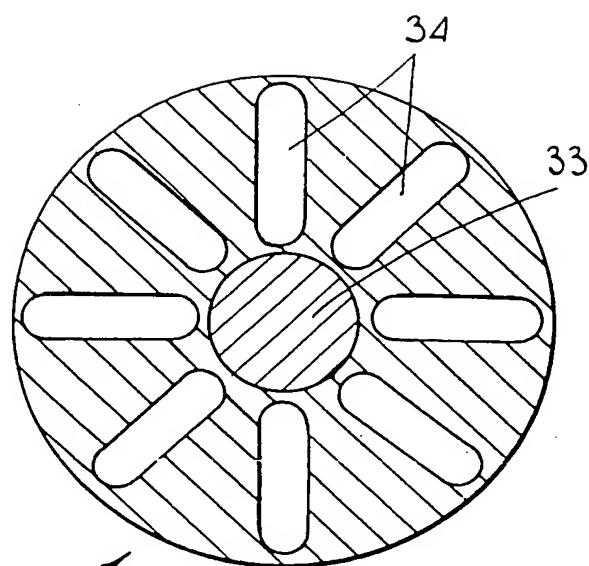


FIG. 3

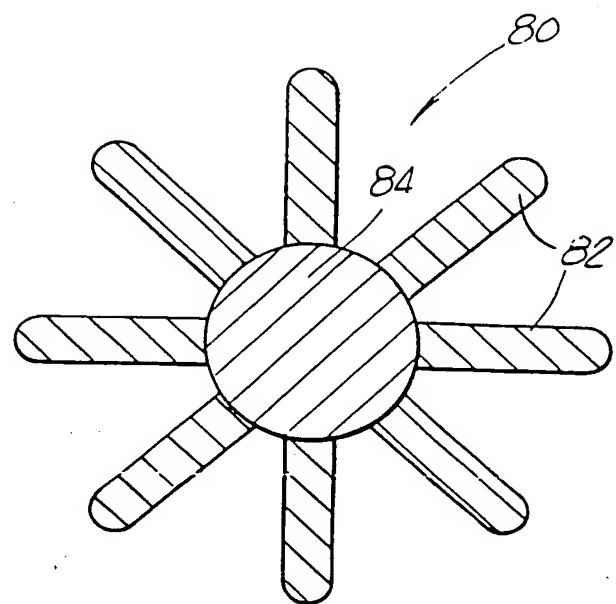


FIG. 4

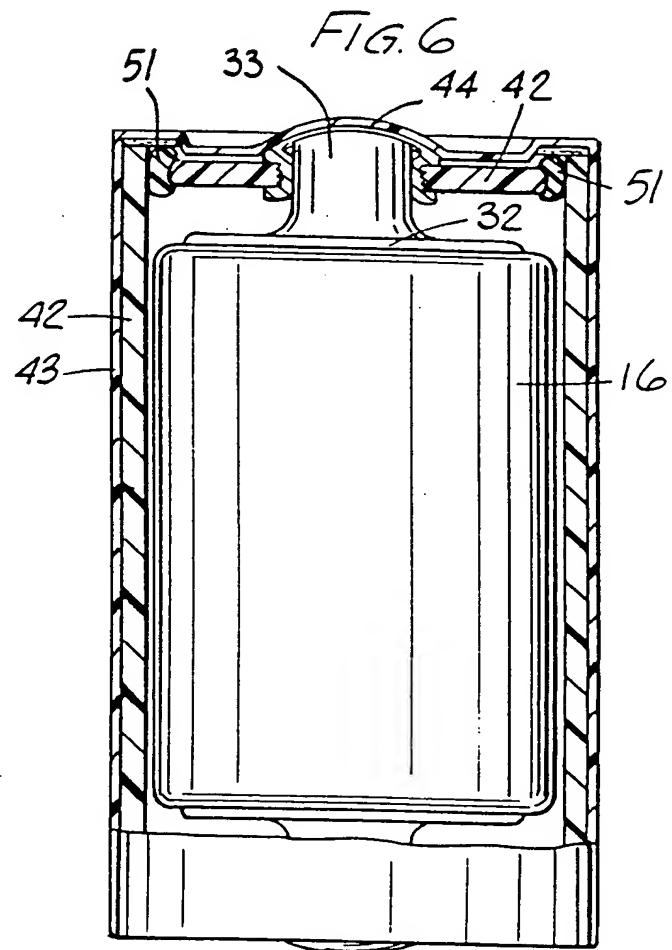
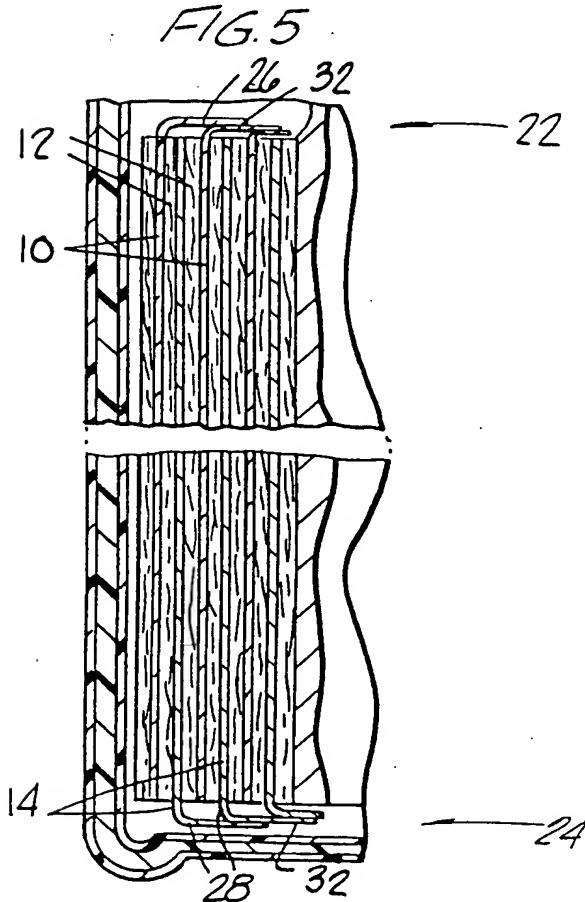
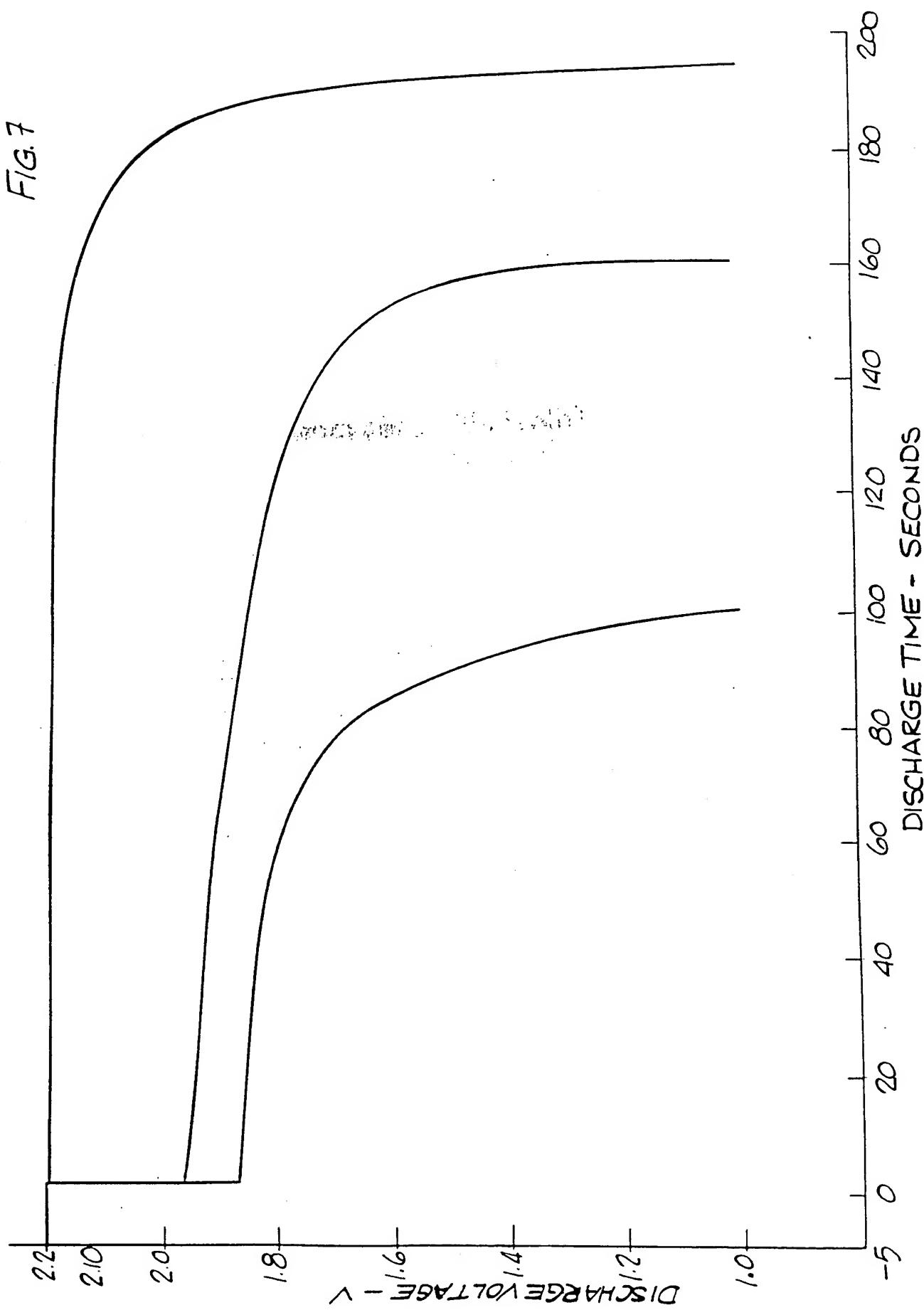


FIG. 6

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FIG. 7



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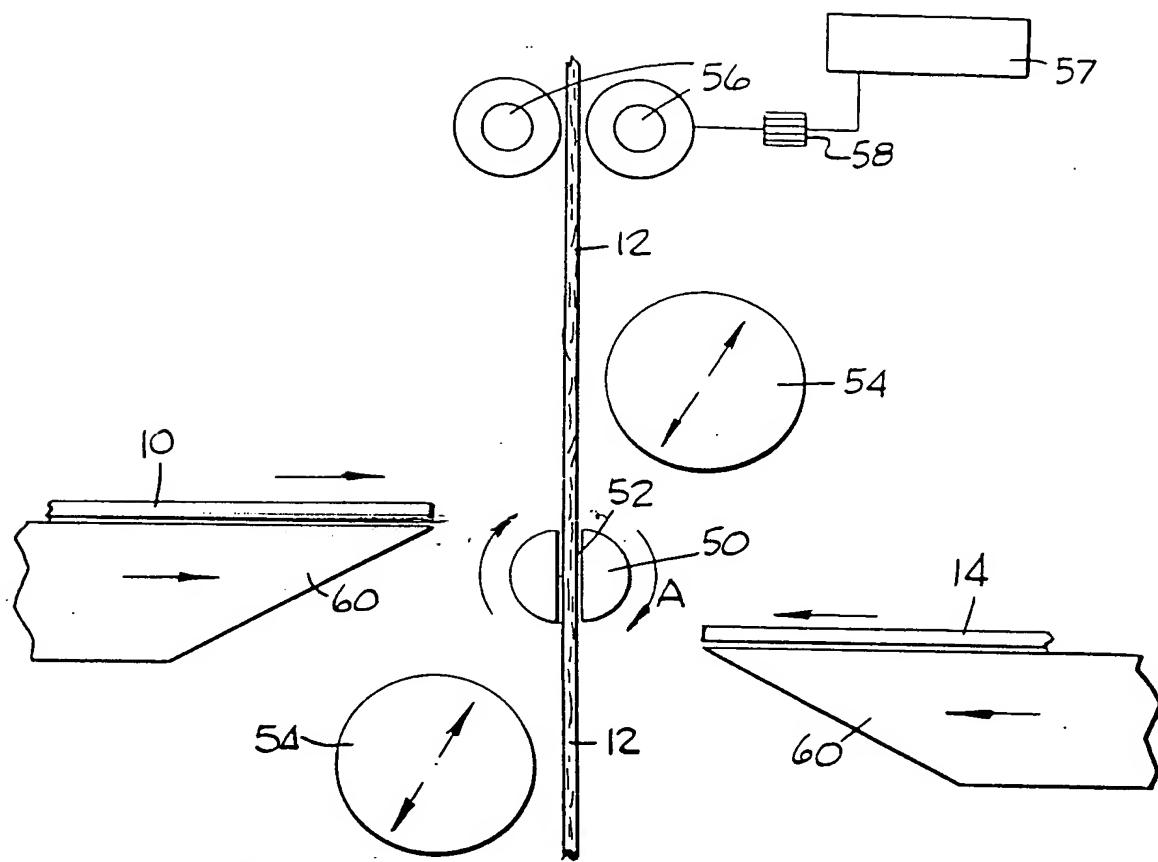


FIG. 8

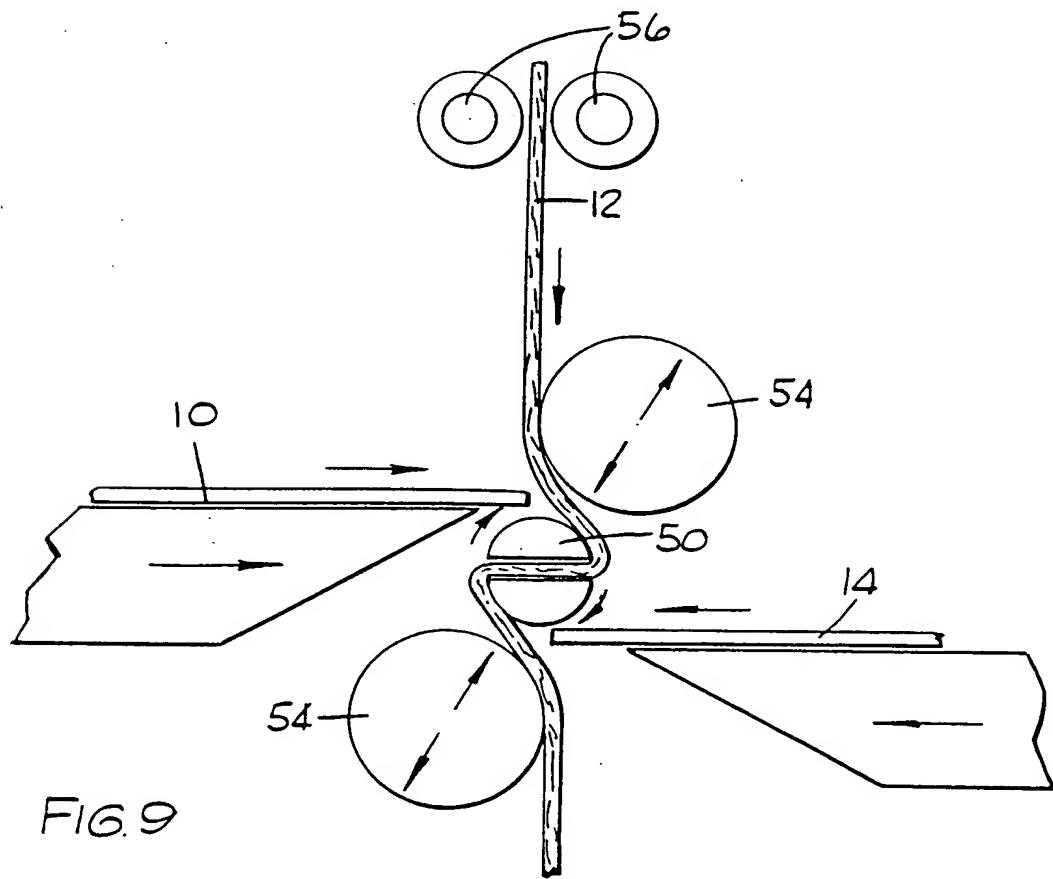


FIG. 9

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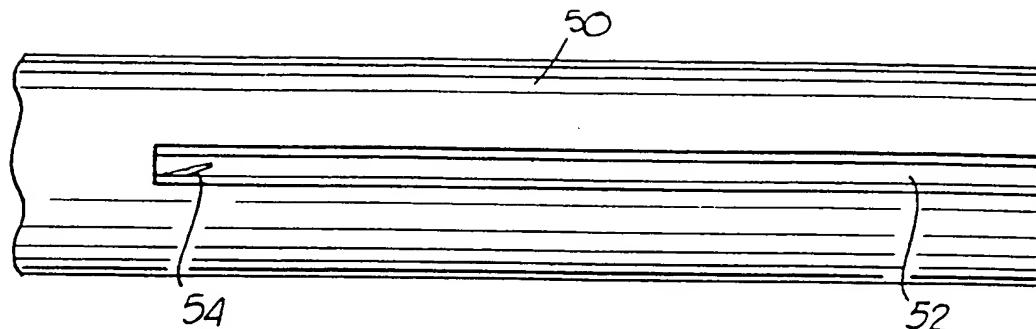


FIG. 10

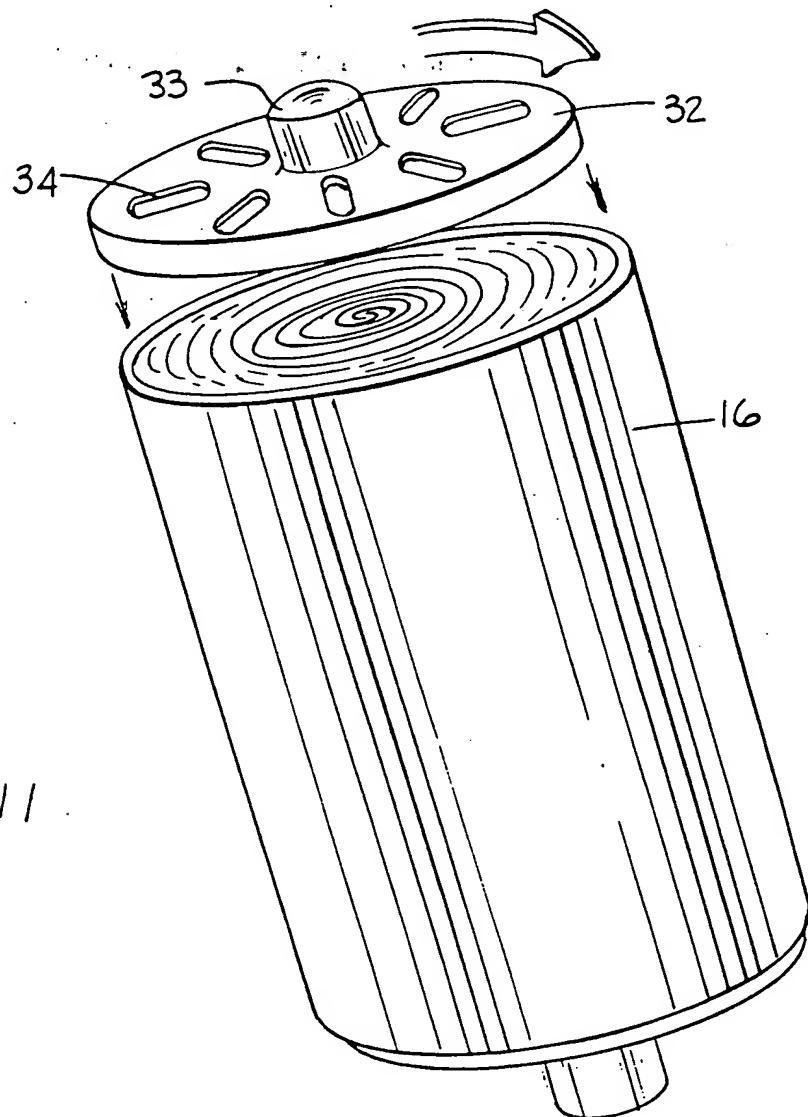


FIG. 11

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# INTERNATIONAL SEARCH REPORT

International Application No. PCT/US90/03428

<b>I. CLASSIFICATION OF SUBJECT MATTER</b> (if several classification symbols apply, indicate all)		
According to International Patent Classification (IPC) or to both National Classification and IPC		
IPC (5): H01M 10/04		
U.S. CL.: 429/94		
<b>II. FIELDS SEARCHED</b>		
Minimum Documentation Searched *		
Classification System	Classification Symbols	
U.S.	29/623.1, 623.3, 623.4 429/94,161, 211, 233	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched		
<b>III. DOCUMENTS CONSIDERED TO BE RELEVANT</b> **		
Category *	Citation of Document, <sup>16</sup> with indication, where appropriate, of the relevant passages **	Relevant to Claim No. <sup>14</sup>
X	US, A, 3,862,861 (McCLELLAND ET AL) 28 January 1975 See column 3, lines 35-36 and 57, and column 4, line 41 - column 5, line 3.	1,5,9-11,15 6-7,12-14
X	US, A, 4,460,666 (DINKLER ET AL) 17 July 1984 See figure 2, and 4, and the entire document	1, 16
Y	US, A, 3,395,043 (SHOELD) 30 July 1968 See figures 1, 2, and 5 and the abstract	6,7,26
Y	US, A, 4,709,472 (MACHIDA ET AL) 01 December 1987 See the entire document	19,20,26
Y	SU, A, 674,124 (LEPERSON ET AL) 20 July 1979 See the abstract and figure 1.	19,20,26
Y	JP, A, 59-103,282 (ENDOU) 14 June 1984 See the abstract and figure 1.	19,20,26
A	JP, A, 56-36860 (SASAKI) 10 April 1981 See the abstract and figure 1.	19-26
<p>* Special categories of cited documents: <sup>15</sup></p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"&amp;" document member of the same patent family</p>		
<b>IV. CERTIFICATION</b>		
Date of the Actual Completion of the International Search *	Date of Mailing of this International Search Report *	
10 SEPTEMBER 1990	5 NOV 1990	
International Searching Authority <sup>1</sup>	Signature of Authorized Official: <sup>15</sup> STEPHEN J. KALAFUT INTERNATIONAL DIVISION For STEPHEN J. KALAFUT <i>Nguyen</i>	
ISA/US		

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